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BIOCLIMATIC CONTROLS IN WESTERN AUSTRALIA

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(Continued from p. 107)

WATER BALANCE

The rainfall of any particular place does not give an exact idea of the moisture condition of that place, because evapo-transpiration must be taken into account. Two places with the same total annual rainfall may have entirely different moisture conditions because the potential evapo-transpiration of one place is high while that of the other place is low. The balance between rainfall and potential evapo-transpiration gives the moisture condition; there are four possible types of moisture balance.

It may happen that the rainfall equals the potential evapo-transpiration, and in this case there is neither water surplus nor water deficit.

When the rainfall is smaller than the potential evapo-transpiration there is a water deficit, the movement of water in the soil is more frequently upwards than downwards, calcium carbonate and other water-soluble salts tend to accumulate in the soil, and plants and animals must be able to overcome the disabilities associated with these conditions.

When the rainfall is greater than the potential evapo-transpiration, some of the water which is not evaporated from the soil or transpired by plants will seep into the ground and be stored there for a while. Only after the whole storage capacity of the ground is filled, will there be any real surplus of water. This surplus water will run off above and below the ground (Map 17). The soil will not show accumulation of calcium carbonate or of other soluble salts because the run-off carries them away in solution.

If rainfall and potential evapo-transpiration are not equal, but their difference is small enough to be stored in the ground when

the rainfall is greater, there is a condition of equilibrium, with soluble matters rising and falling with the movement of water in the ground.

These four possible types of hygrostasis (or water balance) may occur in the same place at different times of the year. There may be months with water excess, months with water deficit, months with increasing or decreasing water storage.

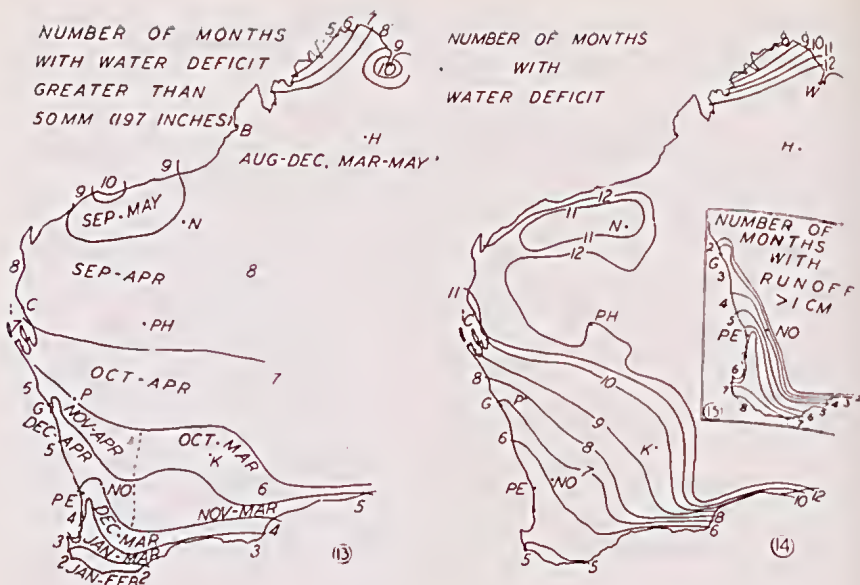
Map 13 shows the average number of months with a water deficit greater than 50 mm. (1.97 inches). It will be noticed that in the mesophytic karri forest there are only two months a year with such a high water deficit. In the remainder of the South-west a more pronounced xerophyly is the natural outcome of the longer dry season. The belts of country with 5 and 6 very dry months are subdivided by the dotted line according to the beginning and the end of the dry season, one month early in the western areas, one month late in the eastern areas. The region with 8 very dry months is divided into two sections. In the southern section, from Carnarvon to Nullagine, there is a continuous very dry season from September to April. Farther north there are two very dry seasons, from August to December and from March to May; summer rains are only sufficient to break the drought for two months, January and February, but June and July are sufficiently cool to reduce evapo-transpiration enough to avoid a bad drought. The western end of the Kimberleys and Wyndham show different drought patterns.

Map 14 shows the number of months per year with any water deficit. This number ranges from less than 5 a year in the mesophytic forest area to 12 months a year in the enormous area extending from Balladonia in the south to Wyndham in the north, and reaching Onslow in the west.

Months with water surplus are shown on Map 17. They cover the whole May-October period along the Darling Scarp and in the karri forest, but they extend from June to October along the coastal plain and in the immediate "rain-shadow" of the Darling Scarp. Perth is in the 4-month belt with surplus from June to September, Northam in the 3-month belt where water surplus does not begin until July. The seasonal distribution, or dispersal, of some bird species, especially water-loving ones, would be controlled by the moving boundaries shown on Map 17.

The distribution of monthly run-off may provide a clue to the present distribution of some fluvifaunal elements, because no fresh-water streams may be expected unless there is a sufficient run-off for a sufficiently long period. It will be seen from Map 15 that the Moore River runs through an area mainly with 5 months of 1 cm. run-off, whereas the Hill River runs through an area mainly with 4 months of 1 cm. run-off. But even the Frankland and the Blackwood Rivers are not free from salinity, because they run through country with a very low incidence of rainfall per wet day, spread over 6 to 8 months.

It will be seen from the table at the end of this paper that the formula for the computation of run-off in the northern regions must



be revised. The torrential downpours of these regions must lead to a rapid run-off with greatly reduced storage.

THE HYGROSTATIC INDEX

The final hygrostatic result is assessed by combining water surplus and water deficit, and water need as expressed by potential evapo-transpiration. This combination may be used as a moisture index. Thornthwaite's moisture index is expressed by the formula

$$\frac{100 \text{ water surplus} - 60 \text{ water deficit}}{\text{water need}}$$

and the values obtained from the application of the formula to Western Australian data are shown on Map 16, and in the appended table. Map 16 therefore shows annual iso-hygrostatic lines, or lines of equal moisture-balance for the year.

Where the annual hygrostasis is over 60 the karri forest develops; it is difficult to say at this stage whether the main characteristics of this forest are due to the high hygrostasis or to the shortness of the dry season, or to both factors.

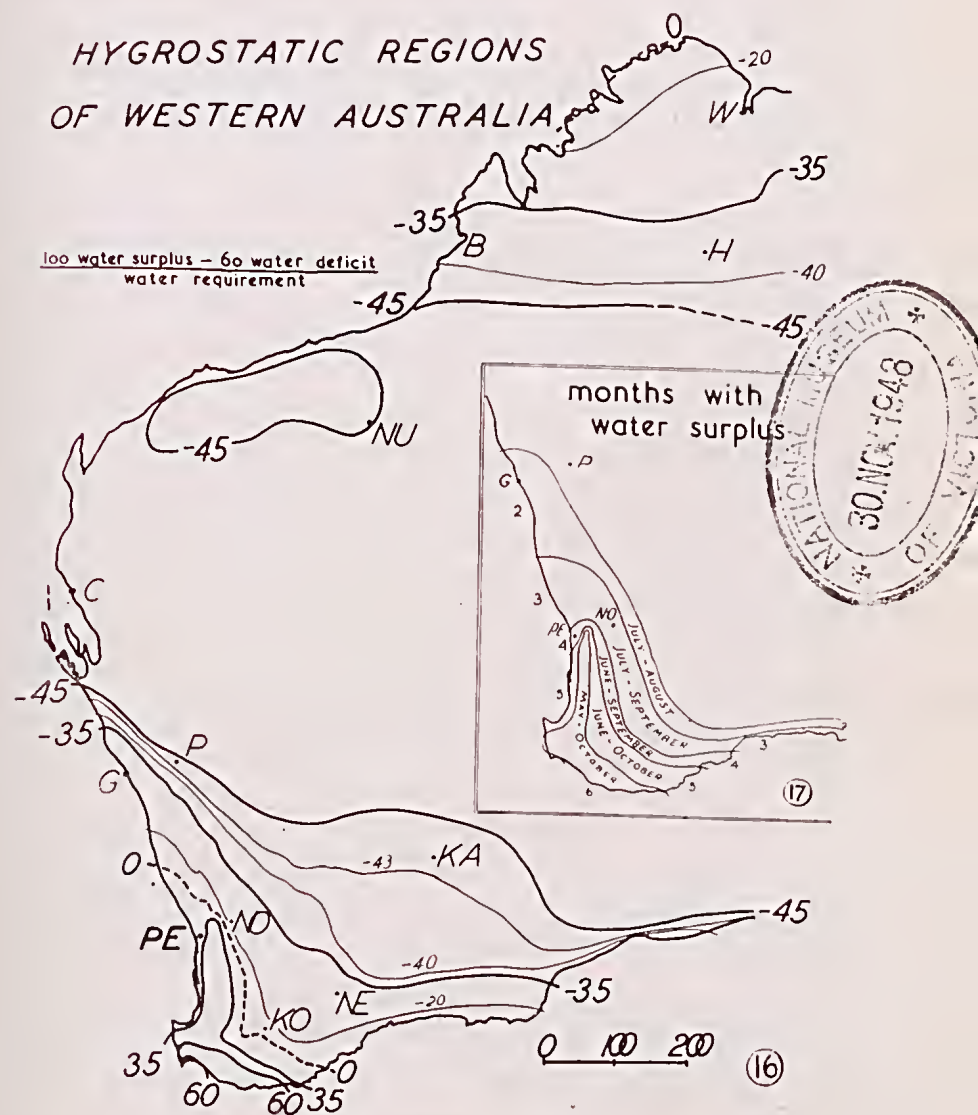
Annual hygrostasis between 35 and 60 favours the growth of forest—with jarrah and marri as dominant species in the South-west. The density of trees is directly controlled by hygrostasis, their sclerophylly by the length of the hot dry season.

Both in the South-west and in the Kimberley Division savanna-woodland is found under moderate hygrostatic conditions, with the index from 35 to —35. This is due to the fact that the savanna-woodland is an intermediate plant formation which results from the merging of forest formations (with strongly positive hygrostasis) with grass or shrub formations (with strongly negative hygrostasis). It must be pointed out that hygrostasis is the only

factor which gives the exact boundaries of the savanna-woodland in both the north and the south of the State at -35 , as these boundaries are outlined by Gardner.

The savanna-woodland belt is bisected by the zero line of perfect hygrostasis (dotted on Map 16), which divides the lime- and salt-losing soils (padalfers) on the positive hygrostasis side, from the lime- and salt-accumulating soils (pedoals) and the transitional soils on the negative hygrostasis side.

With hygrostasis between -35 and -45 the usual plant formation is a sclerophyllous woodland under summer drought (in the South-west), and a grassland under summer rainfall (in the North-west and the Kimberley Division).



Where the hygrostatic index goes beyond —45 trees and soft grasses cannot grow, and specialised shrubs (e.g. mulga) and grasses (e.g. *Triodia*) take their place. The mulga-eucalypt boundary which runs through Pindar, Mount Jackson and Goongarrie corresponds to a —45 hygrostatic; this boundary is not very clearly defined between Mount Jackson and Zanthus because of the very gentle hygrostatic gradient, as shown by the width of the belt between the lines of —43 and —45 on Map 16.

Some very important corridors are probably due to hygrostatic. The narrow coastal belt connecting the Hamersley grassland with the main grassland belt has now climatically disappeared, and there is reason to believe that it is gradually disappearing botanically as well. An increase of 61 mm. (2.4 inches) in the annual rainfall would be sufficient to restore the corridor climatically.

The belt of sclerophyllous woodland which passes through Eyre and south of the Nullarbor Plain is now interrupted, and a decrease of 88 mm. (3.46 inches) in the total annual rainfall would make it disappear altogether. A very slight increase in the total annual rainfall on the contrary would restore a continuous coastal corridor into South Australia.

The woodland belt west of the jarrah forest, on the coastal plain, could be closed by an extension of the forest if the annual rainfall increased by 160 mm. (6.35 inches). This would not be an exceptional climatic change when it is considered that current research undertaken by the writer seems to indicate an increase of 116 mm. (4.58 inches) in the annual rainfall of Perth over the last 68 years.

In case of climatic changes—and we must be ready to admit that climatic changes are going on continuously, although imperceptibly—the first effect to be noticed is a change in the average climatic values. Not very long afterwards some animals may be affected, and plants later on. Soils will be the last to change. This time-lag explains why in some cases climatic, faunal and floral boundaries do not agree very closely among themselves and with soil boundaries.

A final word of caution is necessary in closing this note on bioclimatic controls: even the best agreement between a climatic line and a biological boundary does not imply a causal relationship between the two—it may be entirely due to a coincidence.

CLIMATIC DATA

The following climatic data are expressed in cm. (2.54 cm. = 1 inch) and are listed according to the latitude of the stations for which they have been computed. The columns are arranged in the following order:—

1. Potential evapo-transpiration, January.
2. Water storage in the ground, January.
3. Water deficiency, January.
4. Water surplus, January.
5. Run-off, January.

6. Potential evapo-transpiration, July.
7. Water storage in the ground, July.
8. Water deficiency, July.
9. Water surplus, July.
10. Run-off, July.
11. Hygrostatic index.

	1	2	3	4	5	6	7	8	9	10	11
Pt. George IV	17	10	—	16	8	6	—	5	—	1	4
Wyndham	19	—	—	—	—	9	—	9	—	—	-38
Derby	18	—	—	—	—	5	—	5	—	—	-36
Broome	18	—	3	—	—	4	—	4	—	—	-37
Hall's Creek	18	—	4	—	—	4	—	3	—	—	-38
Port Hedland	19	—	15	—	—	4	—	2	—	—	-48
Roebourne	20	—	15	—	—	4	—	3	—	—	-48
Marble Bar	21	—	14	—	—	2	—	1	—	—	-47
Onslow	19	—	16	—	—	4	—	2	—	—	-50
Nullagine	20	—	12	—	—	2	—	—	—	—	-45
Winning Pool	20	—	17	—	—	4	—	—	—	—	-48
Mundiwindi	19	—	17	—	—	2	—	1	—	—	-47
Carnarvon	16	—	15	—	—	4	3	—	—	—	-47
Peak Hill	19	—	16	—	—	2	—	1	—	—	-48
Hamelin Pool	18	—	17	—	—	3	3	—	—	—	-49
Wiluna	19	—	16	—	—	2	—	—	—	—	-47
Murgoo	19	—	18	—	—	2	3	—	—	—	-49
Cue	20	—	17	—	—	2	2	—	—	—	-48
Sandstone	18	—	16	—	—	2	1	—	—	—	-47
Lawlers	19	—	17	—	—	2	—	—	—	—	-48
Yalgoo	18	—	17	—	—	2	3	—	—	—	-46
Chapman	16	—	15	—	—	3	10	—	6	3	-28
Laverton	18	—	15	—	—	2	—	—	—	—	-46
Geraldton	13	—	13	—	—	4	10	—	5	2	-28
Menzies	17	—	15	—	—	2	1	—	—	—	-45
Watheroo	14	—	13	—	—	2	10	—	4	2	-28
Kanowna	15	—	13	—	—	2	1	—	—	—	-44
Walebing	14	—	13	—	—	2	10	—	7	4	-19
Kalgoorlie	16	—	15	—	—	2	—	—	—	—	-45
Coolgardie	15	—	14	—	—	2	1	—	—	—	-43
Rawlinna	13	—	13	—	—	2	—	1	—	—	-49
Southern Cross	15	—	14	—	—	2	3	—	—	—	-42
Merredin	15	—	14	—	—	2	7	—	—	—	-37
Kellerberrin	15	—	14	—	—	2	7	—	—	—	-38
Northam	15	—	14	—	—	2	10	—	4	2	-28
Eucla	11	—	10	—	—	3	—	1	—	—	-42
Guildford	14	—	13	—	—	3	10	—	14	10	15
York	14	—	13	—	—	2	10	—	4	2	-26
Perth	13	—	12	—	—	3	10	—	14	10	19
Kalamunda	13	—	12	—	1	3	10	—	19	14	44
Rottneet Is.	12	—	11	—	—	4	10	—	11	7	2
Fremantle	12	—	11	—	—	4	10	—	12	8	11
Eyre	11	—	10	—	—	3	1	—	—	—	-38
Balladonia	12	—	11	—	—	3	—	1	—	—	-43
Mandurah	13	—	12	—	1	3	10	—	15	11	24
Wandering	13	—	12	—	—	2	10	—	9	6	2
Narrogin	12	—	11	—	—	2	10	—	6	3	-15
Bunbury	12	—	11	—	—	3	10	—	14	10	27
Collie	12	—	11	—	1	3	10	—	16	12	42
C. Naturaliste	11	—	9	—	—	4	10	—	14	9	20
Donnybrook	12	—	11	—	1	3	10	—	17	13	45
Busselton	12	—	11	—	—	3	10	—	13	9	19
Katanning	13	—	12	—	—	3	10	—	2	1	-22
Esperance	11	—	10	—	—	3	10	—	7	3	-5
Bridgetown	12	—	10	—	1	3	10	—	12	8	27
Karridale	11	—	8	—	1	4	10	—	19	14	63

	1	2	3	4	5	6	7	8	9	10	11
C. Leeuwin	10	—	9	—	1	4	10	—	15	10	32
Mt. Barker	11	—	9	—	—	3	10	—	8	4	10
Albany	10	—	8	—	1	4	10	—	11	7	33
Eclipse Is.	10	—	8	—	—	4	10	—	9	5	17

(The letters on the maps show the following localities: W., Wyndham; B., Broome; H., Hall's Creek; N. and NU., Nullagine; C., Carnarvon; PH., Peak Hill; P., Pindar; G., Geraldton; K. and KA., Kalgoorlie; NO., Northam; PE., Perth; NE., Newdegate; and KO., Kojonup.).

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AN EXPERIMENT IN SWALLOW COUNTING

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The movements of Welcome Swallows (*Hirundo neoxena*) in Australia have been the source of considerable discussion among bird watchers. Over the years there has been much theorising and conjecture. Close observers have long since suspected that the movements of this species do not follow a pattern parallel with that of the European Swallow (*Hirundo rustica*) whose seasonal migrations from the British Isles to Southern Africa and back have been plotted by the recovery of banded birds (*The Swallow*, p. 48, Hoskins and Newberry).

Furthermore, observations on Welcome Swallows appear to indicate that the species does not react to the approaching cold season in South-western Australia as it does in South-eastern Australia. In the South-west Welcome Swallows have been observed in numbers throughout the year. In Victoria and Tasmania bird observers consider that a northward movement occurs.

One evening in May, 1944, I witnessed a remarkable flight of Welcome Swallows at Rockingham in Queensland. Thousands of the birds, all moving in a northerly direction and flying at an altitude